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Continued monitoring for the Knights Ferry Gravel Replenishment Project, Phase 2

A. Project Description: Project Goals and Scope of Work

Carl Mesick Consultants (CMC) is submitting this proposal to continue the environmental studies for the Knights Ferry Gravel Replenishment Project (KFGRP), which was funded by CALFED in 1998. The objective of the KFGRP was to investigate 10 hypotheses regarding the environmental benefits and methods of adding clean gravel to the streambed of the Stanislaus River to improve spawning and incubation habitat for fall-run chinook salmon (*Oncorhynchus tshawytscha*; CMC 2001a). The initial KFGRP studies, which included one year of pre-project studies in fall 1998 and two years of post-project studies in fall 1999 and fall 2000, demonstrated that fall-run chinook salmon will spawn immediately at the tails of pools constructed with newly placed gravel (CMC 2001b). The results also indicated that redd densities were significantly higher in gravel obtained from the Stanislaus River's floodplain compared to similarly-sized gravel imported from the Tuolumne River's floodplain. Redd densities were also higher in Stanislaus River gravel cleaned with a 1/4-inch screen compared to gravel cleaned with a 3/8-inch screen, although the differences were not significant. The results of the second year of post-project studies in fall 2000 indicated that all three types of restoration gravel are rapidly "seasoning" in terms of spawner use (CMC 2001c). Redd densities significantly increased at all three types of restoration gravel relative to the redd densities at control sites in fall 2000 compared to the initial post-project conditions in fall 1999 (Figure 1). CMC hypothesized that chinook salmon probably select spawning sites based on the mineral content or odor of the gravel and the ease of digging a redd (CMC 2001b) and that "seasoning" and fine sediment intrusion affect the suitability of restoration gravel over time. Although the mineral content of the different sources of gravel was not determined during the initial studies, the two sources of gravel differed in color and presumably mineral content and it is likely that the salmon could smell these differences. In addition, salmon frequently construct redds at artificial redd sites, where the construction of the artificial redd in the cemented streambed would have loosened the gravel and facilitated subsequent redd construction. It may also have been easier for salmon to construct redds in the gravel washed with a 1/4-inch screen than in gravel washed with a 3/8-inch screen as it was noticeably easier to dig artificial redds with hoes and shovels in the gravel washed with the smaller screen. Presumably substrate particles between 1/4 and 3/8-inches act as a "lubricant" during redd construction or digging. This project would continue the environmental studies for the KFGRP for a fourth, fifth, and sixth year to evaluate the long-term effects of "seasoning" on chinook salmon spawner use of different sources and sizes of restoration gravel.

The initial KFGRP studies also demonstrated that intragravel dissolved oxygen levels (D.O.) and permeabilities in artificial and natural chinook salmon redds were significantly greater in restoration sites than in control sites (CMC 2001b, 2001c). However, it is not possible to determine whether the survival of chinook salmon eggs to emergence was greater at the KFGRP restoration sites than at the control sites based solely on measurements of D.O. and permeability (CMC 2001b) because the environmental factors that affect egg survival to emergence are poorly understood (Chapman 1988, Young et al. 1990, CMC 2001b). Interpreting the effects of D.O. and permeability on salmonid egg survival is difficult because suspended clay-sized sediment particles can adhere to the egg's membrane and thereby reduce its ability to absorb D.O. (Stuart 1953). This effect is shown in a comparison of three studies of steelhead trout (*O. mykiss*) egg survival relative to D.O. concentration. A laboratory study by Silver et al. (1963), during which eggs were incubated on clean, porous ceramic plates under highly controlled levels of D.O. and flow, indicates that survival was high (about 80%) at D.O. levels of at least 2.5 mg/l (Figure 2). In contrast, a field study by Coble (1961), during which eggs were placed in plastic mesh sacks with gravel, indicates that egg survival gradually declined as D.O. declined from 9.2 mg/l to 2.6 mg/l (Figure 2). Another field study by Phillips and Campbell (1962), during which eggs were placed in perforated metal boxes with glass beads, indicates that no eggs survived at D.O. levels at or below 7.2 mg/l (Figure 2).

Studies with other salmonid species show similar results. Eggs of chum salmon (*O. keta;* Alderdice et al. 1958), chinook salmon (Silver et al. 1963), and coho salmon (*O. kisutch;* Shumway et al. 1964) incubated under clean laboratory conditions survived to hatching at high rates at D.O. concentrations as low as 2.0 to 2.5 mg/l. Chum salmon eggs that were deposited in natural redds in an experimental stream channel with washed gravels also survived at relatively high rates (50%) at D.O. levels as low as 2.5 mg/l (Koski 1975). Conversely, the survival of coho salmon eggs incubated in natural streams either in natural redds (Koski 1966) or in experimental chambers (Phillips and Campbell 1962) were reduced at D.O. concentrations below 9.0 mg/l and 8.3 mg/l, respectively. Although the adhesion of fines to the egg's membranes was not evaluated in the field studies, it is the most likely explanation for why eggs require greater concentrations of D.O. in natural streams than in a laboratory or in washed gravel.

The survival of salmonid eggs is also dependant on intragravel flow rates, which can be measured as either permeability or apparent velocity. Permeability is the ease with which water passes through gravel and depends on the composition and degree of packing of the gravel and viscosity of the water (Pollard 1955). Apparent velocity is the horizontal vector of interstitial flow and is a function of permeability and hydraulic gradient (Pollard 1955; Freeze and Cherry 1979). It is measured as the rate of flow through a standpipe, which is called apparent yield, divided by the porosity of the surrounding gravel. The actual velocity of flow through interstitial spaces, which is called the true or pore velocity, is faster than the apparent velocity because flow travels around substrate particles whereas apparent velocity assumes that the flow path is linear.

Steelhead trout and coho salmon egg survival to hatching in natural streams has been correlated with apparent velocity, but not as strongly as with D.O. concentration; whereas there have been no correlations with permeability (Coble 1961; Phillips and Campbell 1962). The size of coho salmon and steelhead trout embryos at hatching was reduced at low velocities, regardless of D.O. concentration in the lab (Shumway et al. 1964); whereas steelhead trout and chinook salmon egg survival was not correlated with true velocity under the same laboratory conditions (Silver et al. 1963). The survival of masu salmon (*O. masou*) eggs to the eyed stage in 72 redds was somewhat correlated ($r^2 = 0.39$) with an index of intragravel flow in the Kawabe River, Japan

(Kondou et al. 2001). A comparison of five studies, including Gangmark and Bakkala (1960), Coble (1961), Phillips and Campbell (1962), Reiser and White (1988), and Deverall et al. (1993), suggests that the apparent velocity that is critical for egg survival is highly dependant on the intragravel D.O. concentration and possibly the amount of silt adhering to the egg's membrane as well (CMC 2001b).

The effects of suspended fine sediments on the ability of salmon eggs to absorb D.O. is probably quite important in the Stanislaus River, which becomes very turbid during intense rain storms. To study the effects of fines adhering to egg membranes and redd superimposition, this project would directly determine egg survival to emergence rates by planting fall-run chinook salmon eggs in artificial redds while monitoring intragravel D.O. concentrations, apparent velocity, turbidity in the egg pocket, and permeability.

The entombment of alevins is probably another important factor affecting survival to emergence in the Stanislaus River because redd superimposition rates are high (CMC 2001b, 2001c, Mesick 2001a) and the process of redd superimposition frequently covers the superimposed redd with fine sediment. Koski (1966) reported that a majority of mortality in redds was caused by the inability of alevins to emerge. He found numerous dead coho salmon alevins that were completely buttoned-up but extremely emaciated at a depth of 8 inches. Beschta and Jackson (1979) showed that in a flume, fines 0.5 mm in diameter tend to form a barrier in the upper 10 cm of the gravel bed that "seals"against intrusion of fines into the egg pocket but also creates a barrier to emergence. This barrier has been described in salmon redds as a mixture of coarse sand and fines 6 to 12 inches above the egg pocket (Hawke 1978) that has a geometric mean diameter (d_g) that was lower than the substrate above and below the middle layer (Platts et al. 1979).

Previous studies that attempted to quantify alevin entombment relative to the amount of fines have not provided conclusive results. Researchers that evaluated emergence rates by capping natural redds with nets, such as Koski (1966, 1975), Tagart (1976), and EA (1992), did not estimate egg viability, fertilization success, the loss of eggs during deposition in the egg pocket (Young et al. 1990), or the escape of fry that migrate under the trap's netting (Garcia De Leaniz et al. 1993) and so they cannot accurately estimate egg survival to emergence (Chapman 1988, Young et al. 1990). Laboratory studies of the effects of various sand concentrations on emergence rates, such as those by Shelton and Pollock (1966), McCuddin (1977), Tapple and Bjornn (1983), Phillips et al. (1975), tested the ability of large, healthy alevins to emerge under high concentrations of sand, an abnormal condition considering that high concentrations of sand typically result in low D.O. levels and small, weak alevins. These researchers used laboratory troughs with washed gravel and maintained high D.O. levels and either provided high apparent velocities during egg incubation (McCuddin 1977) or planted eyed-eggs (Shelton and Pollock 1966; Tapple and Bjornn 1983) or alevins (Phillips et al. 1975) incubated under optimum conditions. Therefore, their results would predict abnormally high emergence rates if D.O. levels are low when fine sediment intrusion rates are high. These studies indicate that a range of substrate particle sizes, including those $\leq$ 0.85 mm (Shelton and Pollock 1966), $\leq$3.3 mm (Koski 1966), $\leq$4.67 mm (Tapple and Bjornn 1983), and $\leq$6.4 mm (McCuddin 1977), affect entombment rates of alevins.

The quantification of the effect of a sand-silt barrier on entombment of alevins is difficult due to the fragile nature of the barrier. Driving probes to extract freeze cores from egg pockets or driving standpipes into the egg pocket to measure permeability disrupts the sand-silt barrier (Beschta and Jackson 1979). Platts et al. (1979) used a battery of probes to extract a frozen but intact egg pocket that weighed 620 kg; only one was sampled presumably due to the difficulty of working with such a heavy sample.

To compare the survival of chinook salmon eggs to emergence between the restoration sites and the control sites, this project would estimate the rate of egg survival to emergence by planting fall-run chinook salmon eggs in artificial redds and use an index of emergence based on the number of entombed alevins in natural redds that were constructed by similarly sized females.

The fall 1999 and fall 2000 KFGRP studies also indicate that the reconstruction of riffles in mined channels sometimes triggered high rates of fine sediment intrusion during annual pulse flows (CMC 2001b, 2001c). As a result, bed permeabilities declined rapidly at some project sites, thereby potentially affecting spawner use and the survival and emergence of eggs. This project will continue to monitor bed permeability in various reaches of the river.

Sediment transport occurred only at four of the 18 project sites where instream structures, including boulders, mid channel islands and large trees, confined the flow and increased shear stress when flows increased to 3,500 cfs (a moderately high level) approximately seven months after construction. If high flows occur in the next few years, this proposed project will document the effects.

1. Problem

Most Central Valley river ecosystems have been severely degraded over time due to water diversions and land-use practices. The origins of degradation of river ecosystems can be traced back to the 1848 California gold rush, and include the construction of numerous dams, occupation of the floodway, and the mining of gold and gravel from the active channel and floodplain. Gravel and gold mining has been intensive throughout the primary spawning and rearing reaches on the Stanislaus River. A long-time resident of the Stanislaus River corridor reports that inriver mining was particularly intensive during the early 1940s and that draglines were used to excavate both the streambed and part of the floodplain (Frymire, personal communication, see "Notes"). After the peak mining period between 1949 and 1999, Kondolf et al. (2001) estimated that an additional 1,031,800 yd^3 of gravel were extracted from the active channel between Goodwin Dam (RM 58.5) and Oakdale (RM 40). Surveys conducted by the California Department of Fish and Game (DFG 1972) in the 1960s suggest that the riffles were completely excavated from about 55% of the channel between the Knights Ferry County Bridge (RM 54.5) and the Orange Blossom Bridge (RM 47). The few riffles that remain have since become armored and shortened based on a comparison between the DFG surveys conducted in the 1960s and surveys conducted in 1995 and 1996 (Mesick 2001a).

2. Justification

Conceptual Model

Escapement of fall-run chinook salmon to the Stanislaus River has fluctuated between 50 and 35,000 fish since 1946. The fluctuations in escapement are well correlated with streamflow during smolt migration and the number of adult fish that return to spawn (Mesick 2001b). Smolt survival studies with hatchery reared fish suggest that mortality is abnormally high in the deepwater ship channel between Stockton and the confluence with the Mokelumne River and that survival can be improved by either flood flows or a barrier at the head of the Old River which shunts water into the ship channel (Mesick 2001b). One possible explanation for the high mortality rates of hatchery-reared smolts during their 5-10 day migration through the deepwater ship channel in mid April when water temperatures were generally suitable is that striped bass (*Morone saxatilis*) and other predators congregate in the dredged channels and hatchery reared juvenile salmon are particularly susceptible to predation. Another possible explanation for why escapement increases two years after a flood event is that the survival of fry rearing in the San Joaquin mainstem and Delta may be substantially increased during high flows that presumably reduce the impacts of predation, unscreened diversions, contamination, and other stressors. However, there are insufficient data to assess the survival of juvenile salmonids rearing in the Delta.

A stock-recruitment analysis for the Stanislaus River salmon population from 1946 to 1998 suggests that recruitment is frequently limited by an insufficient number of spawners (a.k.a., stock). The analysis indicates that recruitment initially increases as stock increases but then remains constant after stock exceeds about 2,500 three-year-old fish (Mesick 2001b). The number of spawners returning to the Stanislaus River was fewer than 1,500 fish, which was probably low enough to substantially limit recruitment, during 46% of the years from 1958 to 1998. It is likely that the low abundance of spawners was a result of the combined effects of poor smolt survival when springtime flows were low and high ocean harvest rates of adult salmon.

The stock-recruitment analysis also suggests that the habitat in the Stanislaus River can support the progeny of only about 1,250 adult female salmon. It is likely that instream gravel mining, which peaked during the early 1940s prior to the escapement surveys, degraded the quantity and quality of both spawning and rearing habitat in the Stanislaus River. The upstream dams that blocked the coarse sediment supply worsened the problem as the remaining riffles became armored and smaller as they eroded away. The limited amount of riffle habitat in the Stanislaus River results in high rates of redd superimposition during which the late arriving females either excavate and kill the incubating eggs or deposit the fine sediment from their redd on top of the superimposed redd, thereby entombing the alevins. Dr. Mesick observed numerous dead alevins in superimposed redds but few in non-superimposed redds in the Stanislaus River in February and March 2001 (CMC 2001c). Fine sediment intrusion from redd superimposition also tends to reduce the downwelling of surface flow into the redds which increases the influence of oxygen-poor groundwater in the egg pocket. Low D.O. concentrations either kill the embryos or stunt their growth, which reduces their chances for survival (Chapman 1988). The eggs of late arriving female salmon are susceptible to turbid runoff from winter storms in the Stanislaus River that probably coat the eggs with clay-sized particles that would reduce their ability to absorb oxygen. Stunted fry are frequently observed in the screw traps in the San Joaquin tributaries and they are probably quite vulnerable to water temperatures above 65°F, predation, low food availability, contamination, unscreened diversion and other stressors.

It is also likely that loss of riffle habitat from inriver gravel mining reduced rearing habitat and increased predation of juvenile salmonids. Numerous chinook salmon and steelhead/rainbow trout juveniles were observed using the KFGRP riffles, whereas in mined areas, the juveniles are typically restricted to the densely vegetated river margins to avoid predators (Fisheries Foundation, unpublished data, Tom Cannon, personal communication, see "Notes"). Large schools of Sacramento pikeminnow (*Ptychocheilus grandis*) occur in the mined channels and numerous salmonid fry have been observed in their stomachs (Walser and Smith, personal communication, see "Notes").

The construction of new riffle habitat in the primary spawning reach in the Stanislaus River should increase the abundance and condition of the emerging fry, primarily by reducing redd superimposition. Presumably, healthy fry should be able to tolerate warm temperatures, low food availability, and low levels of contamination and avoid predation, unscreened diversion and other stressors better than stunted fry produced in the highly silted, natural riffles in the Stanislaus River. Restoration of riffle habitat should also decrease the abundance of predators, particular Sacramento pikeminnow which feed extensively on fry (Walser and Smith, personal communication, see "Notes"). Although it will be impossible to eliminate predators throughout the system, particularly in the Delta, an increase in the production in healthy smolts should result in increased recruitment to the adult population.

Although gravel augmentation is a logical solution to the problems caused by inriver gravel mining in Central Valley rivers, early restoration projects in the San Joaquin tributaries were poorly used by spawning salmon (Mesick 2001a) and as a result, only a limited number of new projects were being proposed. The early projects imported gravel from the Merced River, used crushed rock, and removed all rock less than 1/2-inch in diameter. Another concern was that salmon clean the gravel during redd construction and there was no evidence to suggest that adding clean gravel to construct spawning habitat would improve egg survival to emergence. Although the initial KFGRP studies helped to resolve these issues, questions remain as to the long-term benefits of gravel augmentation projects.

Hypotheses

Hypothesis 1. The density of fall-run chinook salmon redds will be higher at the restored project riffles than in the unrestored control riffles.

> The density of fall-run chinook salmon redds was studied at 18 project and 7 control riffles in fall 1998 under pre-project conditions and in fall 1999 and fall 2000 under post-project conditions. The results indicate that restoration gravels "season" rapidly such that redd densities substantially increased at the project sites relative to the control sites one year after construction. This project would continue the studies for another three years beginning in fall 2002 at the same KFGRP sites and two new control sites that were evaluated in fall 2000.

Hypothesis 2. Restoration gravel obtained from near the Stanislaus River will be used by more Stanislaus River chinook salmon than will gravel obtained from the Tuolumne River.

The density of fall-run chinook salmon redds was significantly greater ($P = 0.073$) at the sites with Stanislaus River gravel than at sites with similarly-sized Tuolumne River gravel in fall 1999. However, redd densities at the sites with Tuolumne River gravel increased from being lower than those at the control sites in fall 1999 to significantly greater ($P = 0.009$) than those at the control sites in fall 2000. This project will determine whether gravel seasoning has continued since fall 2000.

Hypothesis 3. Restoration gravel between 1/4 and 5 inches will attract more spawners than will gravel between 3/8 and 5 inches.

Although redd densities were consistently greater at the sites with gravel washed with a 1/4-inch screen than at the sites with gravel washed with a 3/8-inch screen in fall 1999 and fall 2000, the differences were not significant ($P \geq 0.37$). This project will collect additional data to test this hypothesis.

Hypothesis 4. Adding gravel without fines to the streambed increases intragravel D.O. concentrations and intragravel flow rates compared to those at the control riffles.

The fall 1999 and fall 2000 studies indicated that D.O. and intragravel flow measured as permeability were significantly greater at artificial and natural chinook salmon redds in restoration riffles than at those in the control riffles. This project will evaluate the effects of four to six years of fine sediment intrusion on intragravel conditions at the restoration riffles in the Stanislaus River.

Hypothesis 5. Restoring riffle habitat with clean gravel will increase egg survival to emergence and the size of emerging fry compared to control riffles.

This hypothesis cannot be evaluated with measurements of intragravel D.O. and flow rates alone due to the influence of clay-sized particles adhering to the eggs. Natural redds will not be capped due to the difficulty in determining both the number of eggs deposited and the number of alevins that escape the net cap (CMC 2001b). Alternatively, chinook salmon eggs from the Merced River Fish Facility will be planted in artificial redds and natural chinook salmon redds will be excavated to estimate alevin entombment rates in project and control riffles.

Hypothesis 6. Riffles constructed in widened, mined channels will have a longer useful life than will riffles constructed in narrow unmined channels.

Following moderately high streamflows of 3,500 cfs in spring 2000, gravel movement occurred at only four of the 18 project riffles where hydraulic controls, such as mid-channel islands, large boulders, or large trees, confined the streamflow and produced high levels of shear stress. This project will continue to monitor bed movement at the 18 project riffles.

Selection of Project Type

The Knights Ferry Gravel Replenishment Project was originally proposed in 1997 as a demonstration project to address two issues regarding restoration. First, no studies had been conducted to determine why salmon spawn at some restoration projects but not others (CMC 2001a). Second, there is uncertainty as to whether adding clean gravel to streambeds would increase the production of healthy juveniles. Although the initial KFGRP environmental studies provide information to help resolve these issues, further studies are needed.

3. Approach

This project includes five tasks, including project management, three years of study, and the preparation of a manuscript for publication in a peer-reviewed journal.

Task 1 Project Management will provide a monitoring plan, invoices, quarterly reports, an oral presentation of results and respond to questions from CALFED or CVPIA managers over the three-year life of the project.
Tasks 2, 3, and 4 will implement the fall 2002, fall 2003, and fall 2004 studies, respectively. The study sites include the 18 KFGRP project riffles, which include TMA, R1, R5, R12A, R12B, R13, R14, R14A, R15, R16, R19, R19A, R28A, R29, R43, R57, R58, and R78, and 9 unrestored control riffles in the Stanislaus River between Goodwin Dam and Oakdale (Figures 3 to 6). Task 5 will prepare a manuscript for publication in a peer-reviewed journal that summarizes all three years of study. Deliverables will include draft and final reports for each year of study and a copy of the manuscript prepared for publication. Draft reports will be sent for review to the Stanislaus Fish Group, all other biologists working in the Stanislaus River basin, and the CALFED or CVPIA program managers. The following describes the approach to be used for each year of study to evaluate six hypotheses regarding the benefits and methods of restoring spawning habitat for fall-run chinook salmon at the KFGRP sites.

Hypotheses 1, 2, and 3. The effects of the source and size of restoration gravel on spawner use will be tested using the following methods:

> Redds will be counted and mapped at each study site at 10-day intervals from mid-October through mid-December as was done for the initial KFGRP studies. Contour maps showing bed elevations in 1-foot intervals will be generated showing the precise location of each redd at each study site. If the density of redds continues to be significantly correlated with distance downstream from Goodwin Dam, the barrier to upstream migration, two-tailed *F*-tests will be used to compare the residual variances, slope, and elevations of regressions of redd density versus distance downstream between the project and control sites (Snedecor and Cochran 1989, pages 390-393). The addition of the two new control sites (riffles R2 and R44) should improve the likelihood of detecting actual differences in spawner use.

Hypothesis 4. Adding gravel without fines to the streambed increases intragravel D.O. concentrations and intragravel flow rates compared to those at the control riffles.

> This study element will evaluate the effects of four to six years of fine sediment intrusion on intragravel conditions at 18 restoration riffles in the Stanislaus River. Intragravel D.O. and permeability will be measured at a depth of 12 inches in undisturbed gravel and in the vicinity

of egg pockets of natural redds with a modified Terhune standpipe. Measurements will be made in undisturbed gravel in early November. Up to five non-superimposed redds will be measured at each riffle in early November and another five will be measured after turbid storm runoff has occurred, presumably in January. If the tailspills of superimposed redds are sufficiently intact to locate the egg pocket, up to 25 superimposed redds will be measured project riffles and another 25 will be measured in control riffles in November and January. The age of each measured redd will be determined from redd mapping for the study of Hypotheses 1, 2 and 3. It will be assumed that an egg pocket is located near the upstream edge of the tailspill in the middle of the redd as reported in the literature (Vronskiy 1972, Hawke 1978).

Hypothesis 5. Restoring riffle habitat with clean gravel will increase egg survival to emergence and the size of emerging fry compared to control riffles.

This hypothesis cannot be evaluated with measurements of intragravel D.O. and flow rates alone and so chinook salmon eggs from the Merced River Fish Facility will be planted in artificial redds to estimate egg survival to emergence and natural chinook salmon redds will be excavated to estimate alevin entombment rates. Three hundred water-hardened eggs will be buried at a depth of 12 inches in fully enclosed egg incubation chambers, approximately the size of 5-gallon buckets, contained within natural looking artificial redds. Six artificial redds will be constructed in each of three types of gravel: (1) restoration gravel washed with a 1/4-inch screen, (2) restoration gravel washed with a 3/8-inch screen, and (3) natural gravel at control sites. These 18 artificial redds will be constructed in early November immediately following a managed pulse flow. It is anticipated that some of these artificial redds will be superimposed by spawning female chinook salmon and it should be possible to detect these effects. Another six artificial redds will be constructed in gravel washed with a 1/4-inch screen in mid-December. It is anticipated that turbid storm runoff will occur prior to the hatching of these eggs, but that redd superimposition rates will be low. It should be possible to detect the influence of fine sediments adhering to the egg's membrane by comparing the survival of eggs planted and intragravel turbidity levels in mid-December to those in early November. Intragravel measurements of D.O. concentration, water temperature, apparent velocity, and turbidity will be monitored at each artificial redd at 10-day intervals during the 100-day incubation and alevin development period. These data will be used to develop a model to estimate egg survival to emergence based on measurements of intragravel conditions alone. Apparent velocity will be measured with a KVA Model 40L Geoflo Groundwater Flowmeter inserted into slotted well pipe buried in each artificial redd (CMC 2001c). The flowmeter produces a heat pulse of about 500 degrees Fahrenheit and uses four pairs of opposed thermistors that surround the heat source to determine the magnitude and direction of flow. Bed permeability will be measured at a depth of 12 inches adjacent to the incubation chamber immediately after planting the eggs and immediately prior to excavating the chamber approximately 110 days later. A chamber to collect emerging fry will not be attached until just prior to emergence to minimize the potential for vandalism, which can be a problem because the Stanislaus River is used by numerous recreational boaters during the incubation period. Alevins that successfully emerge will be sedated, measured to the nearest millimeter, quickly blotted dry and then weighed to the nearest 0.01 grams. Approximately 110-days after planting, the incubation chambers will be retrieved and the number and condition of entombed alevins and dead eggs will be evaluated. Survival rates of the test eggs will also be monitored at the hatchery. The sediment size distribution will be determined for dried substrate samples collected from layers where dead eggs and entombed alevins occur in the incubation baskets. It is recommended that this study should be conducted for three years to ensure that an adequate number of replicates will be collected to determine survival to emergence rates relative to gravel size, redd superimposition, and turbid storm runoff. The number and size of emerging alevins will be compared between sites differing in gravel size, redd superimposition, and turbidity using standard ANOVA methods. Conducting the study over three years will also permit modifications of the incubation chamber and study design if necessary.

A second method will be used to test Hypothesis 5 that focuses on the effect of redd superimposition on the entombment of alevins in natural salmon redds. Restoration gravel is typically cleaned with a 1/4-inch or larger screen such that most of the 3-7 mm diameter sand that affects entombment rates has been eliminated from the restoration gravel (CMC 2001b). Therefore, it is likely that entombment rates should be lower at the restoration sites than in the control sites. Although the incubation chamber studies described above will evaluate the effects of redd superimposition, construction of artificial redds may not create a natural sand barrier within the redd or its effects on entombment. As an index of the number of entombed alevins observed in natural salmon redds, salmon redds constructed by similarly sized females will be excavated to count the number of entombed alevins. The precise location of all redds will be determined with a total station and the size of females constructing the redds will be measured to the nearest millimeter at three riffles with gravel washed with a 1/4-inch screen, three riffles with gravel washed with a 3/8-inch screen and at three control riffles. Approximately 120 days after redd construction, 15 superimposed and 15 non-superimposed redds will be excavated in each gravel type with a hand-held shovel. Redds will be selected that are constructed by similarly-sized females to minimize differences in fecundity and at nearby sites to minimize differences in egg losses due to predators or high velocities that can sweep eggs away during spawning. Alevins and eggs will be collected in large dip nets with 1/8-inch mesh held immediately downstream from the redd. Dead alevins and eggs will be covered in white fungus making them easy to observe and collect. The number of dead alevins and eggs will be compared between the gravel types and between superimposed and non-superimposed redds using two-sample *t*-tests.

Hypothesis 6. Riffles constructed in widened, mined channels will have a longer useful life than will riffles constructed in narrow unmined channels.

Streambed elevations will be measured relative to monuments established in summer 1999 at the 18 project riffles with a total station. Measurements will be made at each site along a single transect established in November 1998 or September 1999, a 15- to 20-foot grid pattern, and at major changes in grade along the streambank and channel bottom. The elevation data will be collected as X, Y, Z coordinates that are stored electronically within the total station and then downloaded to a laptop computer. The data will then be converted into AutoCAD DXF format files. The DXF files will then be imported into a software program called Terrain Version 3.1 developed by Softree Technical Systems to generate the contour maps in one-foot intervals. Changes in bed elevation will be assessed using both the transect data and the contour map.

It is recommended that these studies should be conducted for three years to ensure that an adequate number of replicates has been collected and that a range of escapement, streamflow, and turbid storm runoff have been evaluated.

4. Feasibility

All study elements, except for planting eggs in incubation chambers, have been successfully implemented by CMC for the initial KFGRP environmental studies. Although egg planting studies can suffer from high failure rates, CMC will follow the techniques used by other researchers who conducted successful studies. To avoid the problems encountered by other studies, CMC will plant eggs within 24 hours of water-hardening and use large incubation chambers to minimize the possibility of eggs contacting the chamber's wire mesh.

CMC has attached signed agreements with the landowners granting access to all study sites.

5. Performance Measures

The objective of this project is to obtain sufficient field data to evaluate the six hypotheses described above. The following describes the Performance Measures, Metrics, Targets and Baseline for this objective.

Performance Measures: Environmental Indicators will include estimates of spawner use relative to the source and size of gravel, measures of the quality of salmonid egg incubation habitat, chinook salmon egg survival to emergence, and the development of a model suitable for estimating chinook salmon egg survival relative to measurements of intragravel conditions. Specific program actions will be measured according to the production of the deliverables.

Metrics: Environmental Indicators to assess spawner use will include redds/yd^2 at restored and control riffle habitats. The quality of salmonid egg incubation habitat will be measured in terms of intragravel dissolved oxygen concentration and bed permeability in undisturbed gravel and chinook salmon redds, and apparent velocity and turbidity will also be measured in artificial redds. Chinook salmon egg survival will be measured as (1) a percentage of planted eggs that survive to emergence in incubation chambers and (2) an index based on the number of entombed alevins and dead eggs in natural salmon redds. Program actions will be measured in terms of reports and manuscripts produced.
Targets: The metrics for the Environmental Indicators will be that sufficient data are collected to detect true differences with the tests for each of the six hypotheses and that a model can be developed to accurately estimate chinook salmon egg survival to emergence based on habitat measurements.

Baseline: Spawning habitat studies in the Stanislaus River conducted by CMC from fall 1994 to fall 1997 (Mesick 2001a) and for the KFGRP environmental studies from fall 1998 to fall 2000 provide baseline data for this project.

6. Data Handling and Storage

Field data will be entered onto standardized forms that provide specific spaces for the data required for each task. Field supervisors will confirm that all data have been accurately recorded before leaving the study sites by initialing each form. Data collected electronically, such as with a total station, will be stored on hard media, such as a CD. All data analysis will be conducted using standard software programs, such as *Corel* Quattro Pro. Copies of all raw data files, map files, and final analysis files will be submitted to CALFED or CVPIA, if requested.

7. Expected Products/Outcomes

Draft and final reports will be submitted for the Task 2 Fall 2002 Studies, Task 3 Fall 2003 Studies, and Task 4 Fall 2004 Studies. For Task 5, a manuscript describing all three years of study will be submitted to CALFED or the CVPIA and a peer-reviewed journal for publication. If requested by CALFED or CVPIA, oral presentations will be made at annual review meetings.

8. Work Schedule

Assuming that the project is recommended for funding, a contract could be executed by September 2002. Task 1 Project Management would begin immediately and continue throughout the life of this project. Task 2 Fall 2002 Studies would begin as soon as the contract is executed and it would be completed by August 2003, when the final report will be submitted. Task 3 Fall 2003 Studies would begin in October 2003 and it would be completed by August 2004, when the final report will be submitted. Task 4 Fall 2004 Studies would begin in October 2004 and it would be completed by August 2005, when the final report will be submitted. Task 5 Manuscript Preparation would begin in summer 2005 and it would be completed by August 2005.

B. Applicability to CALFED ERP and Science Program Goals and Implementation Plan and CVPIA Priorities.

1. ERP, Science Program and CVPIA Priorities

This project will help achieve the CALFED ERP, Science Program, and Anadromous Fish Restoration Program goals to improve our understanding of at-risk species, such as fall-run chinook salmon, in the San Joaquin region and to conduct adaptive management experiments. The KFGRP had a positive effect on adult reproduction, egg survival, and juvenile rearing for fall-run chinook salmon and possibly steelhead trout as well. This project, which would continue the KFGRP environmental studies, should provide important information needed for the management of these species.

Another priority of the CALFED Science Program is to advance the understanding of ecosystem processes. This project will improve our understanding of the long-term benefits of restoring riffle habitat in mined channels.

This project's targets will contribute to achieving the CVPIA Section 3406(b) goal of doubling the natural production of anadromous fish in the Central Valley over levels that existed between 1967-1991 as well as the goal to restore and replenish, as needed, spawning gravels on the upper Sacramento, American, and Stanislaus rivers [relative to Section 3406(b)(13)]. The US Fish and Wildlife Service has identified the lack of and accessibility to quality stream channel and riparian habitat, as well as spawning gravel availability and suitability as limiting factors for anadromous fish.

2. Relationship to Other Ecosystem Restoration Projects.

CMC, with assistance from McBain and Trush, Smith and Walser Enterprises, and other subcontractors, will begin implementing a large-scale restoration project on the Stanislaus River in fall 2001 that will investigate the importance of restoring functional floodplain habitat adjacent to restored riffle habitat. The Anadromous Fish Restoration Program will fund work at Two-Mile Bar where both the floodplain and riffle habitat will be restored. The Four-Pumps Mitigation Agreement will fund work at Lovers Leap where riffle habitat will be restored but the floodplain will remain heavily encroached with riparian vegetation and constricted by dikes. CMC and Smith and Walser Enterprises will design the riffles to benefit both fall-run chinook salmon and steelhead trout. They will also conduct studies to evaluate the hypothesis that steelhead trout require cover and feeding stations adjacent to their spawning habitat. McBain and Trush will conduct fluvial geomorphic studies to evaluate the effect of a functional floodplain on sediment transport at the restored riffles.

CMC is submitting a proposal titled the Frymire Ranch Project to CALFED in October 2001 that will increase the scope of the above project. By increasing the number of restoration sites, the environmental studies will be strengthened by increasing the number of replicates and it is hoped that it will be possible to detect a population response in terms of increased smolt production and increased escapement.

CMC and Smith and Walser Enterprises are partnering with the Friends of the Tuolumne River to submit a proposal to CALFED in October 2001 to restore spawning habitat for steelhead trout adjacent to Bobcat Flat on the Tuolumne River. McBain and Trush would be restoring the floodplain habitat at Bobcat Flat. If funded, the environmental studies for this project would be integrated with CMC's projects on the Stanislaus River to increase our understanding of the importance of floodplain habitat and flow regimes to salmonid populations.

S.P. Cramer and Associates, California Department of Fish and Game, Fisheries Foundation, CMC, and Smith and Walser Enterprises will submit a proposal to CALFED in October 2001 to study the impact of predation on salmonid production in the Stanislaus River. The restoration of riffle habitat in dredged channels for the KFGRP has reduced the abundance of predators based on reports from professional fishing guides (Walser and Smith, personal communication, see "Notes"). This proposed project would demonstrate the effect of restoring riffle habitat on predation rates and identify the most important predators and their habitat.

The U.S. Fish and Wildlife Service has contracted with the Fisheries Foundation to survey juvenile and adult salmonid habitat use in the Stanislaus River in 2000 and 2001. This study indicated that numerous juvenile chinook salmon and juvenile rainbow/steelhead trout were utilizing the KFGRP riffles constructed in summer 1999 whereas few juveniles were observed in the channels mined for gravel. It is anticipated that this study will continue.

CALFED funded CMC to implement the Knights Ferry Gravel Replenishment Project that added 13,000 tons of gravel at 18 sites between Two-Mile-Bar and the city of Oakdale in summer 1999. This project tested the source, size and placement of gravel for spawning habitat. The results of the KFGRP were used to design this project.

The Commercial Fishermen Salmon Stamp Program funded the Stanislaus Fly Fishermen and the Department of Fish and Game to add 1,000 to 2,000 tons of gravel each year to three sites in the Stanislaus River approximately one mile downstream from Goodwin Dam in 1996 and 1997. The CVPIA Section 3406(b)(13) program provided funds to add more gravel to one site in 2000. The Four-Pumps Mitigation Agreement funded the construction of three riffles as spawning habitat for chinook salmon in the Stanislaus River at River Miles 47.4, 50.4 and 50.9 in 1994. These riffles were poorly used by spawning salmon and most of the gravel was quickly eroded away partially due to the boulder weirs constructed at the site boundaries. The weirs were intended to stabilize the gravel, but instead increased turbulence and bed shear stress.

3. Requests for Next-Phase Funding

This proposal is requesting next-phase funding for the Knights Ferry Gravel Replenishment Project, #97-N21, to continue the environmental studies. All tasks for the KFGRP should be completed by December 2001. A detailed summary of the KFGRP is provided as an attachment to this proposal.

4. Previous Recipients of CALFED Program or CVPIA funding.

CMC received funding from CALFED for the Knights Ferry Gravel Replenishment Project, #97-N21, which added 13,000 tons of clean gravel to 18 sites on the Stanislaus River from Two-Mile Bar to the city of Oakdale in August 1999.

CMC has contracted with the AFRP, USFWS Agreement Number 11332-J003, for the project titled "Spawning Habitat and Floodplain Restoration in the Stanislaus River, Phase 1, Two-Mile Bar. Work is expected to begin in winter 2001.

CMC's project, "Spawning Habitat and Floodplain Restoration in the Stanislaus River, Phase 1, Lovers Leap, has been recommended for funding from the Four-Pumps Mitigation Agreement. The contract is expected to be executed by March 2002.

5. System-Wide Ecosystem Benefits

The increased awareness of the importance of fluvial geomorphic processes to ecosystem health and sustainability and the damage caused by instream gravel mining, both speak to the need for this project. The primary ecological objective of this project is to restore gravel and rebuild riffles in spawning reaches of the Stanislaus River, where instream gravel mining has reduced the quantity and quality of habitat for fall-run chinook salmon and steelhead/rainbow trout. This project will improve our understanding of how best to restore severely damaged habitat in a river that has highly regulated streamflows. Other projects that employ different designs to restore spawning and rearing habitat for salmon and trout are underway in the Tuolumne, Merced and other Central Valley rivers, and the results of this project should be applicable to all gravel augmentation projects in the Central Valley.

C. Qualifications

Carl Mesick Consultants, which was founded in 1992, will implement this project. Dr. Carl Mesick will manage this project and directly supervise all field work. He received his Ph.D. in fisheries science from the University of Arizona in 1984. He has twenty years of experience as a fisheries scientist evaluating the effects of water diversions, hydroelectric operations, stream restoration projects, timber harvest, and mine operations on trout, salmon, non-game species of fish, and invertebrates. Dr. Mesick's expertise includes stream habitat restoration and studies of instream flow, water temperature, riparian vegetation, sedimentation, entrainment at diversion intakes, food availability, fish passage, fish habitat preference, fish population monitoring, and stream habitat classification. He has studied the spawning habitat of fall-run chinook salmon on the Stanislaus River since 1994. Dr. Mesick manages and supervises all phases of the Knights Ferry Gravel Replenishment Project funded by CALFED, including project design, environmental compliance and permitting, construction supervision, and the monitoring of salmonid spawning habitat. He has managed other large, multi year projects for the City of Los Angeles Department of Water and Power, Southern California Edison, and the Electric Power Research Institute. Dr. Mesick recently worked as a Habitat Restoration Coordinator for the U.S. Fish and Wildlife Service's Anadromous Fish Restoration Program.

D. Cost

1. Budget.

The estimated cost for Task 1 Project Management is $11,215, Task 2 Fall 2002 Studies is $134,514, Task 3 Fall 2003 Studies is $129,015, Task 4 Fall 2004 Studies is $129,597, and Task 5 Manuscript Preparation is $7,800. The total project cost is $412,141. If only a portion of this project were to be funded, Tasks 1 and 2 could be funded separately for $145,729 or in combination with any of the other tasks.

2. Cost-Sharing

No funds have been allocated to provide cost-share for this project.

E. Local Involvement

A summary of this proposal was distributed to the Stanislaus Fish Group, which consists of agency and consulting biologists active on the Stanislaus River, for their review and comment. Dr. Mesick lead a two-hour discussion of limiting factors for salmonids in the Stanislaus River with the Stanislaus Fish Group on 21 August 2001 that included the impacts of instream mining. CMC will distribute all draft and final task reports to the Stanislaus Fish Group for comment. Public outreach will be achieved by reporting study results to the Oakdale Leader, the local newspaper, and The Record, a newspaper for the City of Stockton. CMC also works closely with the local representatives of California Trout and biology teachers at the local community college.

F. Compliance with Standard Terms and Conditions.

CMC will comply with all state and federal terms.

G. Literature Cited

Alderdice, D.W., W.P. Wickett, and J.R. Brett. 1958. Some effects of exposure to low dissolved oxygen levels on Pacific salmon eggs. Journal of the Fisheries Research Board of Canada 15:229-250.

Beschta, R.L. and W.L. Jackson. 1979. The intrusion of fine sediments into a stable gravel bed. Journal of the Fisheries Research Board of Canada 36: 204-210.

[CMC] Carl Mesick Consultants. 2001a. Task 3 Pre-project Evaluation Report, Knights Ferry Gravel Replenishment Project. Produced for the CALFED Bay Delta Program and the Stockton East Water District. Revised July 2001, El Dorado, California.

[CMC] Carl Mesick Consultants. 2001b. Task 5 Initial Post-project Evaluation Report, Knights Ferry Gravel Replenishment Project. Review draft produced for the CALFED Bay Delta Program and the Stockton East Water District. August 2001, El Dorado, California.

[CMC] Carl Mesick Consultants. 2001c. Task 6 Fall 2000 Post-project Evaluation Report, Knights Ferry Gravel Replenishment Project. Review draft produced for the CALFED Bay Delta Program and the Stockton East Water District. Forthcoming, El Dorado, California.

G. Literature Cited (Continued)

Chapman, D.W. 1988. Critical review of variables used to define effects of fines in redds of large salmonids. Transactions of the American Fisheries Society 117 (1):1-21.

Coble, D.W. 1961. Influence of water exchange and dissolved oxygen in redds on survival of steelhead trout embryos. Transactions of the American Fisheries Society 90:469-474.

[DFG] California Department of Fish and Game. 1972. Report to the California State Water Resources Control Board on effects of the New Melones Project on fish and wildlife resources of the Stanislaus River and Sacramento-San Joaquin Delta. Produced by Region 4, Anadromous Fisheries Branch, Bay-Delta Research Study, and Environmental Services Branch.

Deverall, K.R., J.R.M. Kelso, and G.D. James. 1993. Redd characteristics and implications for survival of chinook salmon (*Oncorhynchus tshawytscha*) embryos in the Waitaki River, New Zealand. New Zealand Journal of Marine and Freshwater Research. 27:437-444.

[EA] EA Engineering Science, and Technology. 1992. Report of Turlock Irrigation District and Modesto Irrigation District Pursuant to Article 39 of the License for the Don Pedro Project. Appendices 6 through 8 of Fisheries Studies Report. Report prepared for Turlock Irrigation District and Modesto Irrigation District. Lafayette, California.

Freeze, R.A. and J.A. Cherry. 1979. Groundwater. Prentice Hall, Inc., Englewood Cliffs, New Jersey.

Gangmark, H.A. and R.G. Bakkala. 1960. A comparative study of unstable and stable (artificial channel) spawning streams for incubating king salmon at Mill Creek. California Fish and Game 46: 151-164.

Garcia De Leaniz, C., N. Fraser, and F. Huntingford. 1993. Dispersal of Atlantic salmon fry from a natural redd: evidence for undergravel movements? Canadian Journal of Zoology 71:1454-1457.

Hawke, S.P. 1978. Stranded redds of quinnat salmon in the Mathias River, South Island, New Zealand. J. Marine and Freshwater Research 12(2):167-171.

Kondolf, G.M, A. Falzone, and K.S. Schneider. 2001. Reconnaissance-level assessment of channel change and spawning habitat on the Stanislaus River below Goodwin Dam. Report prepared for the U.S. Fish and Wildlife Service, Sacramento, CA. 22 March 2001.

Kondou, T, N. Takeshita, A. Nakazono, S. Kimura. 2001. Egg survival in a fluvial population of masu salmon in relation to intragravel conditions in spawning redds. Transactions of the American Fisheries Society 130:969-974.

Koski, K.V. 1966. The survival of coho salmon (*Oncorhynchus kisutch*) from egg deposition to emergence in three Oregon streams. Master's thesis. Oregon State University, Corvallis.

Literature Cited (Continued)

Koski, K.V. 1975. The survival and fitness of two stocks of chum salmon (*Oncorhynchus keta*) from egg deposition to emergence in a controlled-stream environment at big beef creek. Doctoral dissertation, University of Washington, Seattle.

McCuddin, M.E. 1977. Survival of salmon and trout embryos and fry in gravel-sand mixtures. Master's thesis. University of Idaho, Moscow.

Mesick, C.F. 2001a. Studies of spawning habitat for fall-run chinook salmon in the Stanislaus River between Goodwin Dam and Riverbank from 1994 to 1997. Fish Bulletin 179: in press.

Mesick, C.F. 2001b. Factors that potentially limit the populations of fall-run chinook salmon in the San Joaquin River tributaries. Unpublished manuscript, El Dorado, CA.

Phillips, R.W. and H.J. Campbell. 1962. The embryonic survival of coho salmon and steelhead trout as influenced by some environmental conditions in gravel beds. Pacific Marine Fisheries Commission 14th Annual Report for the year 1961: 60-75.

Phillips, R.W., R.L. Lantz, E.W. Claire, and J.R. Moring. 1975. Some effects of gravel mixtures on emergence of coho salmon and steelhead trout fry. Transactions of the American Fisheries Society 104(3): 461-466.

Platts, W.S., M.A. Shirazi, and D.H. Lewis. 1979. Sediment particle sizes used by salmon for spawning with methods for evaluation. U.S. Environmental Protection Agency Ecological Research Series EPA-600/3-79-043.

Pollard. 1955. Measuring seepage through salmon spawning gravel. Journal of Fisheries Research Board of Canada 12(5): 706-741.

Reiser, D.W. and R.G. White. 1988. Effects of two sediment size-classes on survival of steelhead and chinook salmon eggs. North American Journal of Fisheries Management 8:432-437.

Shelton, J.M., and R.D. Pollock. 1966. Siltation and egg survival in incubation channels. Transactions of the American Fisheries Society 95(2):183-187.

Shumway, D.L., C.E. Warren, and P. Doudoroff. 1964. Influence of oxygen concentration and water movement on growth of steelhead trout and coho salmon embryos. Transactions of the American Fisheries Society 93(4):342-356.

Silver, S.J., C.E. Warren, and P. Doudoroff. 1963. Dissolved oxygen requirements of developing steelhead trout and chinook salmon embryos at different water velocities. Transactions of the American Fisheries Society 92: 327-343.

Sommer, T.R., M.L. Nobriga, W.C. Harrell, W. Batham, and W.J. Kimmerer. 2001. Floodplain rearing of juvenile chinook salmon: evidence of enhanced growth and survival. Can. J. Fish. Aquat. Sci. 58: 325-333.

Literature Cited (Continued)

Snedecor, G.W. and W.G. Cochran. 1989. Statistical Methods. Iowa State University Press. Ames.

Stuart, T.A. 1953. Spawning migration, reproduction, and young stages of lock trout (*Salmo trutta* L.). Scottish Home Department, Freshwater and Salmon Fisheries Research 5, Edinburgh.

Tagart, J.V. 1976. The survival from egg deposition to emergence of coho salmon in the Clearwater River, Jefferson County, Washington. Master's thesis. University of Washington, Seattle.

Tappel, P.D. and T.C. Bjornn. 1983. A new method of relating size of spawning gravel to salmonid embryo survival. North American Journal of Fisheries Management 3: 123-135.

Vronskiy, B.B. 1972. Reproductive biology of the Kamchatka River chinook salmon [*Oncorhynchus tshawytscha* (Walbaum)]. Journal of Ichthyology 12: 259-273.

Young, M.K., W.A. Hubert, and T.A. Wesche. 1990. Comments: fines in redds of large salmonids. Transactions of the American Fisheries Society 119(1):156-162.

Notes

Fisheries Foundation. Unpublished data. Work conducted under contract to the U.S. Fish and Wildlife Foundation. Concord, California.

Cannon, T. 2001. Senior Biologist with HDR Engineering, Inc., Folsom, California. Personal communication with Dr. Mesick on 21 August 2001.

Frymire, P. 2000. Long-term resident of the Stanislaus River corridor, Frymire Road, Knights Ferry, California. Personal communication with Dr. Mesick in March 2000.

Walser S, and T. Smith. 2001. Sierra West Adventures, business partners and professional fishing guides on the San Joaquin tributaries, Sonora, California. Personal communication with Dr. Mesick on 10 February 2001.

ATTACHMENT 1

SUMMARY OF THE KNIGHTS FERRY GRAVEL REPLENISHMENT PROJECT

The National Fish and Wildlife Foundation executed a contract with Carl Mesick Consultants to implement the Knights Ferry Gravel Replenishment Project (KFGRP) on 30 September 1998. By 31 March 1999, applications were submitted for all environmental permits and by 15 August 1999, copies of all the permits were submitted to NFWF and CALFED. Construction began on 4 August 1999 and was completed by 24 September 1999. A total of 13,000 tons of gravel was placed at 18 project sites in the Stanislaus River between Goodwin Dam and Oakdale: Six sites received a total of 4,490 tons of Stanislaus River rock 1/4 to 5 inches in diameter; another six sites received a total of 5,570 tons of Stanislaus River rock 3/8 to 5 inches in diameter; and six other sites received a total of 2,940 tons of Tuolumne River rock 3/8 to 5 inches in diameter. The total cost of the project will be approximately \$659,882. CALFED provided \$561,407, the Stockton East Water District provided approximately \$90,000, and Carl Mesick Consultants donated approximately \$8,475 in labor and expenses for project management.

The KFGRP environmental studies were divided into three tasks:

- Task 3, Pre-Project Habitat Evaluations, which documented baseline conditions at the 18 project sites and 7 control sites in fall 1998 and summer 1999;
- Task 5, Initial Post-Project Habitat Evaluations, which documented spawning and incubation conditions in fall 1999; and
- Task 6, Second Year Post-Project Habitat Evaluations, which documented spawning and incubation conditions in fall 2000.

The Task 3 studies produced contour maps of all study sites showing the pre-project streambed elevation in August 1999 and the location of where fall-run chinook salmon spawned in fall 1998. The density of salmon redds was significantly correlated with the distance downstream from Goodwin Dam, the barrier to upstream migration. To compare redd densities between control and project sites, two-tailed F-tests were used to compare the residual variances, slope, and elevations of the regressions between redd density and distance downstream. The F-tests indicated that there were no significant differences in redd density between the control sites and the unmined portions of the project sites. Although the redd densities at the mined portions of the projects sites were substantially lower than those at the control sites, it was not possible to conduct statistical tests because the densities at the mined sites were not correlated with distance downstream.

The Task 3 studies also indicate that conditions for the survival of salmonid eggs were quite poor. The percentage of particles finer than 1 mm in 50 subsurface substrate samples averaged 11.3% and ranged from 0.23% to 35.8%. The mean permeability of 123 measurements in undisturbed gravel was 3,129 cm/hr. The mean intragravel dissolved oxygen concentration at 77 standpipe sites was 9.5 ppm and 18% of the measurements were below 8 ppm, which may be low enough to result in high rates of egg mortality. Dissolved oxygen concentrations below 11 ppm, which occurred at 70% of the standpipe sites in fall 1998, probably result in the production of small, weak alevins that were unlikely to survive (Chapman 1988). The fall 1998 measurements of intragravel dissolved oxygen were made prior to turbid storm runoff, which is typically correlated with substantial declines in dissolved oxygen (Mesick 2001a). It was not possible to collect samples after the rain storms began due to increased flows for flood control.

The Task 5 initial post-project studies indicated that the source of gravel for restoring riffles significantly affected fall-run chinook salmon spawner use and that intragravel dissolved oxygen concentrations and permeabilities were significantly higher in artificial and natural redds in the restored riffles than in control riffles. The density of salmon redds was significantly greater ($P = 0.073$) at the sites with Stanislaus River gravel than at sites with similarly-sized Tuolumne River gravel in fall 1999. Although redd densities were about 29% higher where the gravel was cleaned with a 1/4-inch screen than at sites where the gravel was cleaned with a 3/8-inch screen, the difference was not significant ($P \geq 0.370$). The results also suggest that chinook salmon are equally likely to spawn at restoration riffles created by adding gravel to extensively mined channels, naturally flat channels, or the natural tails of pools.

Bed permeabilities at the project riffles declined at most sites following turbid storm runoff in January and February 2000. After a controlled pulse flow for smolt outmigration in spring 2000, permeabilities increased at most sites although very little bed mobilization occurred, but decreased at the upstream half of riffles in a recently mined reach near Lovers Leap. The Lovers Leap reach contains a large volume of fine sediment stored on the streambed and presumably, the addition of gravel triggered the movement of the fines into the riffles. Thermographs buried in artificial redds showed that intragravel water temperatures began to deviate from surface temperatures when the pulse flow and presumably fine sediment intrusion began. Deviations between intragravel and surface water temperatures were correlated with declines in intragravel dissolved oxygen concentrations below 8 ppm, which are probably lethal to incubating eggs.

The Task 6 studies, which were conducted in fall 2000, indicate that the restoration gravel "seasoned" after one year in that chinook salmon redd densities increased in all three types of restoration gravel relative to the redd densities at the control sites when compared to the fall 1999 results. In addition, intragravel dissolved oxygen concentrations and permeabilities remained high in artificial and natural redds in the restored riffles compared to samples collected in control riffles during fall 2000. Apparent velocity was measured with a KVA Model 40L Geoflo Groundwater Flowmeter in slotted wells buried in artificial redds. Apparent velocity declined from an average of 7.2 feet/hour at newly constructed redds to 0.9 feet/hour immediately after a pulse flow that was intended to attract spawners. There were no significant differences in apparent velocity between project riffles and control riffles or at superimposed and non-superimposed redds following the pulse flow. During future studies, the artificial redds will be constructed after the pulse flow to better simulate the conditions at most of the natural redds.

A final report for the Task 3 studies and a draft report for the Task 5 studies are available at the CALFED web site. A draft report for the Task 6 studies is approximately 60% completed and it should be distributed for review by late-November 2001.

Dr. Mesick gave two presentations on the results of the KFGRP environmental studies. One, which was titled "Spawning habitat restoration in the Stanislaus River" was presented at the CALFED Science Conference 2000 in Sacramento on 3 October 2000. The other, which was titled "Egg incubation conditions in restored riffles in the Stanislaus River", was presented at the American Fisheries Society Annual Meeting in Santa Rosa on 31 March 2001.

Independent observations by professional fishing guides and other fishery biologists indicate that the KFGRP riffles provide excellent habitat for adult steelhead trout and juvenile chinook salmon and rainbow/steelhead trout. Mr. Steve Walser and Mr. Tim Smith, who are professional fishing guides, report that angling for steelhead trout has greatly improved at the KFGRP sites where surface turbulence and deep water provide cover and feeding habitat (Walser and Smith, personal communication). Trevor Kennedy with the Fisheries Foundation, and Tom Cannon, Senior Biologist with HDR Engineering, snorkeled some of the KFGRP sites and report that numerous juvenile salmon and trout utilize the KFGRP riffles, whereas few use the nearby mined channels.

This project should be completed by December 2001.